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Effects of Exotic Fuelwood Removal on Groundwater Levels in the Middle Rio Grande Bosque

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Effect of Exotic Fuelwood Removal on Groundwater Levels in the Middle Rio Grande Bosque

Final Report

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Inter-Agency agreement between the U.S. Forest Service Rocky Mountain Research Station and and the U.S. Fish and Wildlife Service Bosque Improvement Initiative.

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A Joint Venture Agreement between the USDA Forest Service, Rocky Mountain Researcher Station (RMRS), Albuquerque, and the University of New Mexico Water Resources Program (WRP)

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Table of Contents

Table of Contents 2
List of Tables 3
List of Figures 3
Introduction 4
Methodology 4
  Study Objectives 4
  Study Design 5
  Groundwater Monitoring and Data Collection 6
  Additional Data Sets 7
  Software 8
Results To Date 8
  Project Milestones 8
    Grants and Presentations 9
    Assisting Riparian Restoration in the MRG 9
  Maps, distance to river and groundwater time series 9
  The Groundwater Hydrological Regime in the MRG Bosque 16
    Spring Floods 16
    Summer Monsoons 16
  Fire in the MRG Bosque 20
Discussion 22
  Research Concerns and Opportunities 22
    Technical Difficulties 22
    Recent Site Developments 22
    Analytical Challenges 22
  Future Work to be Performed 22
Acknowledgments 23
Literature Cited 23

List of Tables

Table 1. Summary of Site Treatments 6
Table 2: North Site Wells Calculated Distances to Riverbank 10
Table 3: Middle Site Well Calculated Distances to Riverbank 12
Table 4: South Site Well Calculated Distances to Riverbank 14

List of Figures

Figure 1. North Site Well Locations 10
Figure 2: North Site Wells - Summer Groundwater Time Series 11
Figure 3: North Site Wells - Winter Groundwater Time Series 11
Figure 4. Middle Site Well Locations 12
Figure 5: Site Wells - Summer Groundwater Time Series 13
Figure 6: Middle Site Wells - Winter Groundwater Time Series 13
Figure 7. Middle and South Site Well Locations 14
Figure 8: South Site Wells - Summer Groundwater Time Series 15
Figure 9: South Site Wells - Winter Groundwater Time Series 15
Figure 10: Preliminary Overview of Full Groundwater Record, Middle Block 16
Figure 11. Average monthly precipitation at Albuquerque Airport 17
Figure 12. Average monthly precipitation at Bosque del Apache, ... 18
Figure 13. Daily Discharge of the Rio Grande at Albuquerque, 2005 18
Figure 14. Daily Discharge of the Rio Grande from North to South, 2005 19
Figure 15: Daily Discharge of the Rio Grande at Albuquerque, 2006 19
Figure 16. Linear Model of Response of Groundwater to River, Middle 2 North Well, 2005 20
Figure 17: North 3 South Well, Autumn 2006, Post Wildfire 21
Figure 18: North 3 South Well, Spring 2007, Wildfire Regrowth 21

Introduction

Throughout the southwest, riparian ecosystems have been transformed by anthropogenic impacts on natural river environments. Dams, irrigation canals and other human structures have altered the natural frequency, duration and intensity of spring floods floods. Floodplain water tables have dropped and invasive species such as saltcedar (*Tamarix ramosissima*) and Russian olive (*Elaeagnus angustifolia*) now dominate areas formerly inhabited by flood-adapted native cottonwoods (*Populus deltoides spp.*) and willows (*Salix ssp.*)(Busch and Smith 1995).

1. Invasive vegetation, particularly saltcedar, creates high loads of woody fuels, thereby increasing the frequency and intensity of uncontrolled fires in the riparian forest. Such high-intensity fires cause high mortality among flood-adapted native woody vegetation. In contrast, the non-native woody species are more fire adapted than the native woody species and can rapidly replace the native species in the wake of catastrophic wildfires, leading to a non-native dominated, fire-adapted ecosystem(Smith et al. 2004).

The USDA Forest Service Fuels Reduction Study (FRS) is investigating the effects of non-native woody vegetation and fuel removal on multiple parameters of riparian ecology. Here we consider the hydrology portion of the FRS, in which the groundwater hydrology at treatment sites was continuously monitored over time. In addition, a number of sites have burned since the study began, allowing for the consideration of the effect of catastrophic fire on groundwater hydrology parameters.

In December of 2005, the University of New Mexico Water Resources Program (WRP) entered into a Joint Venture with the USDA Forest Service to provide continued monitoring, storage, and analysis of the groundwater portion of the FRS. Since that time, all groundwater data has been subject to quality assurance and quality control (QAQC). In addition, all groundwater data has been merged into a single database and compared to relevant hydrological parameters including river flow, and subject to visualization and preliminary analysis. This report details the progress of the groundwater portion of this study completed to date. Finally, two Professional Projects are currently being prepared based on the groundwater section of the FRS pursuant to the requirements of the WRP curriculum.

Methodology

Study Objectives

This research was designed to quantify the interaction between the removal of non-native woody species and groundwater levels. In addition, the interaction between catastrophic fires and groundwater levels was considered. The main objectives of this project were to:

- accurately measure variations in groundwater levels over time to characterize the properties

of riparian groundwater;

- compare differences in groundwater level variations between control, treatment, and fire sites;
- develop robust, low-cost methods for storage, retrieval, and analysis of high-quality regional hydrological data;
- and provide high-quality regional hydrological data to other researchers working to develop a better understanding of the linkages between the wide array of environmental factors in the Middle Rio Grande ecosystem including riparian restoration.

Study Design

Three randomized treatment blocks (North, Middle and South) were selected to serve as replicates for proposed treatments as shown in Table 1. Each block was divided into four sites. A randomized block design was created to assign each of the four sites within each block to either a control (CONTROL) or one of three treatment groups.

Initially, all treatment groups were subject to non-native woody vegetation removal treatments followed by herbicide application. Then three further treatments were employed in each block, one per site. Further treatments included:

- chipping and spreading of removed fuels on-site (CHIP);
- chipping and spreading of removed fuels on-site followed by revegetation with native woody species (CHIP+PLANT);
- and piling and controlled burning of removed fuels on-site (BURN).

Several sites that had experienced catastrophic wildfire prior to study initiation were included. In addition, several sites have experienced catastrophic wildfire since monitoring began. Monitoring continued at these sites and they were replaced, when possible, by other "extra" sites of the same treatment class (WILDFIRE). Consequently, the three treatment blocks contain 18 sites with 36 wells total. The sites range in size from 7.66 to 50 hectares in area.

Bock and Site	Area (ha)	Treatment Type	Dates of Treatments Performed
North 1	16.07	CONTROL	Control Site
North 2	18.33	CHIP+PLANT	2002-Nov./2003-Nov.
North 3	17.03	CHIP	2003-Apr./2004/Apr. Fire June 2006
North 4	23.43	BURN	2002-Nov./2003-Apr.
Middle 1	19.41	CHIP	2002-Nov./2004-Mar.
Middle 2	29.17	BURN	2004-Oct./2004-Dec.
Middle 3	13.21	CHIP+PLANT	2004-Apr.
Middle 4	18.78	WILDFIRE	2002-May/2004 June
Middle 5	15	WILDFIRE	2000-May
Middle 6	16.44	WILDFIRE	2000-May
Middle 7	35	CONTROL	Control Site
South 1	28.87	CONTROL	Control Site
South 2	15.54	CHIP+PLANT	2003-Feb./2003-Apr.
South 3	26.71	BURN	2002-Nov./2003-Feb.
South 4	15.45	CHIP	2002-Nov./2003-Feb.
South 5	14.44	WILDFIRE	Fire June 1996
South 6	7.66	WILDFIRE	Fire June 1996
South 7	50	WILDFIRE	Fire May 2003

Table 1. Summary of Site Treatments

Groundwater Monitoring and Data Collection

Groundwater monitoring wells were installed, one each at the north and south end of each site. Each monitoring well consists of a 5.08 cm (2 inch) interior diameter galvanized steel tube that is between to 3 and 4 meters in length. The bottom meter of each well was screened across the water table with 0.5 mm (0.020 inch) slotted screen. The well hole was hand-augured and the well tube was hand-driven into the bore hole. Each well extends approximately 80 cm above the soil surface and was fitted with a padlocked well cap. This design allows the wells to withstand

wildfires without appreciable damage.

Each well was fitted with a vented-cable In Situ miniTroll data logger. Each logger has measured the groundwater temperature and depth every 15 minutes. Groundwater monitoring commenced in October of 2002, and continues at present. Starting in late 2005, all times were recorded in Mountain Standard Time (MST, UTC-7) to allow comparison with periods during Daylight Savings Time (DST).

Standardized field notes have been collected during each data collection trip since early the WRP took over the project in early 2005. Since that time, at each visit to each well, the following data have been manually collected:

- a groundwater level measurement obtained with a measuring tape water level indicator;
- a GPS waypoint (including exact timestamp and approximate elevation);
- and high resolution digital photographs in each cardinal direction plus up (canopy) and down (groundcover).

The manually collected data, together with the automatically collected logger data, have been compiled into a centralized database. Automatically collected data have been subject to an automated validation protocol to guard against mechanical and operator error, and then compared to manually collected data to provide quality assurance and quality control (QAQC). Backups of the database and all support files have been regularly prepared and stored off-site.

Additional Data Sets

A number of tables were prepared at the beginning of the study. These tables have been transferred, when necessary, into a digital format and centralized to allow for easy comparison. These tables include:

- coordinates of well location and time of installation;
- time-line of treatment progress and other events effecting sites, along with actions taken;
- and ecological site descriptions performed at time of well installation, including soil profile and topography surveys.

Relevant regional data sets have been obtained to facilitate analysis of hydrological data. These include:

- Topographical data sets for use in creation of GIS base maps. The locations of each well were added to the base maps. Data sets included:
  - New Mexico base maps of counties and hydrological unit codes (HUCs), obtained from the New Mexico Resource Geographic Information System (available at http://rgis.unm.edu/);

- transportation, elevation, and LandSat layers from the USGS Seamless Data Distribution System (available at http://seamless.usgs.gov);
- and locations of USGS river gaging stations from the USGS National Water Information System;

- and Rio Grande high frequency (15 minute interval) discharge measurements for relevant gaging stations from the USGS National Water Information System (available by request at http://waterdata.usgs.gov/nwis).

Software

Data storage, visualization and analysis have been conducted using open source software wherever possible. In particular, the following open source software has been employed:

- the Perl programming language (Wall and Schwartz 2000) was used to process and verify text, particularly logger data files;
- the Openoffice suite (available at http://www.openoffice.org) was used to interface the database to enter manually collected data into the database;
- the Postgresql database (available at http://www.postgresql.org) was used design and operate a centralized database with which to store and retrieve all project data;
- the PostGIS GIS database plugin (available at http://postgis.refractions.net)was used to store regional GIS data and conduct spatial queries, including distance from well to riverbank;
- the R programming language(R Core Development Team 2007) was used to visualize and analyze hydrological data;
- and Qgis (available at http://qgis.org) was used to create GIS basemaps.

Results To Date

Project Milestones

The key accomplishments of the project that have been completed in 2006-7 are as follows:

- field measurements have accurately quantified the pipe height and cable length at each well, allowing for calculation of the distance from soil surface to groundwater;
- lithium batteries have replaced standard alkaline batteries in data loggers, providing for longer and more reliable logger life spans;
- photo points have been taken at each well and well-visit in each cardinal direction, allowing

for rapid qualitative site assessment over time;

- preliminary slug tests were conducted to estimate variability of hydrological conductivity in the vicinity of each well.
- field measurements have quantified the location and elevation of each well to within +/- 5 meters using a consumer-grade GPS unit;
- well locations and elevations have been visualized in relation to salient hydrological features such as rivers and canals using GIS software;
- automated validation of logger data has been conducted, including identification and exclusion of mechanical and operator error, physically unrealistic outliers, and data gaps of less than three hours;
- accuracy and precision of data loggers has been assessed by comparing validated logger data with manual water level depth measurements;
- a central, search-enabled database has been constructed to store all project data, including groundwater data and regional GIS data;
- and a secure web portal has been established to centralize and coordinate project activities and work products.

Grants and Presentations

A competitive $4,500 grant was applied for in October 2006 and was awarded March 2007 through the University of New Mexico's Graduate Research Development Fund (GRD). The grant is to be used to replace aging equipment and to rent a mapping grade GPS unit to measure the elevation of each wellhead.

A poster on this research was presented at the 2006 New Mexico Water Research Symposium, the 2007 National Groundwater Association conference in Albuquerque, NM, and the 2007 Student Water Symposium at University of New Mexico (Gunning 2007). The poster was awarded "Best Poster" at UNM's Student Water Symposium.

Assisting Riparian Restoration in the Middle Rio Grande

In 2006, an overview of the groundwater record in the Middle block of the project facilitated project planning for southwestern willow flycatcher (*Empidonax trailii extimus*) and Rio Grande silvery minnow (*Hybognathus amarus)* habitat restoration in the Isleta Reach by Parametrix under the direction of the Rio Grande River Endangered Species Act Collaborative Program (Jones 2007).

Maps, distance to river and groundwater time series

Qgis was used map well locations with respect to the main river channel and other features of hydrological importance, including USGS LandSAT and transportation layers and the MRGCD irrigation network. Most monitoring wells are close to the Rio Grande riverbank. PostGIS was used to calculate this distance for each well where the riverbank was defined by the USGS

National Hydrography Dataset.

Time series of the collected groundwater data for summer and winter of 2005 are shown alongside site maps. Substantial intra-site and inter-site variability is evident, particularly in the summer, when variability due to both climactic influences and anthropogenic irrigation is high. No diurnal cycle is evident in the winter, suggesting that the observed diurnal groundwater cycle is caused primarily by evapotranspiration. Finally, an overview of the full period of record in the Middle block is shown in Figure 10. Yearly periodicity is evident in this overview, as well as significant inter-site and inter-year variability.

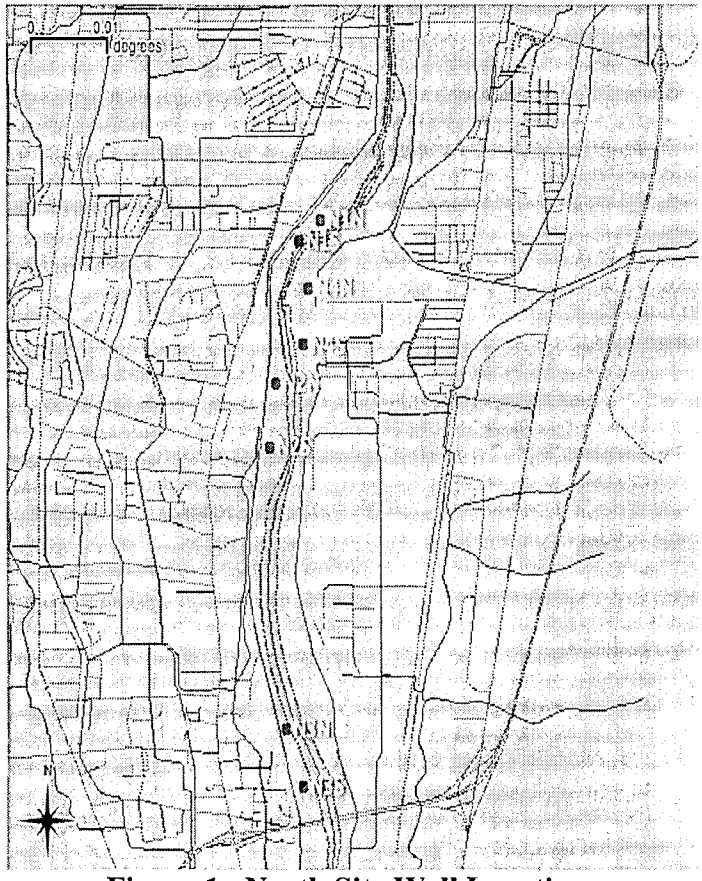

Figure 1. North Site Well Locations

Well ID	Meters to River
N1N	140
N1S	34
N2N	146
N2S	232
N3N	46
N3S	115
N4N	218
N4S	105

Table 2: North Site Wells Calculated Distances to Riverbank

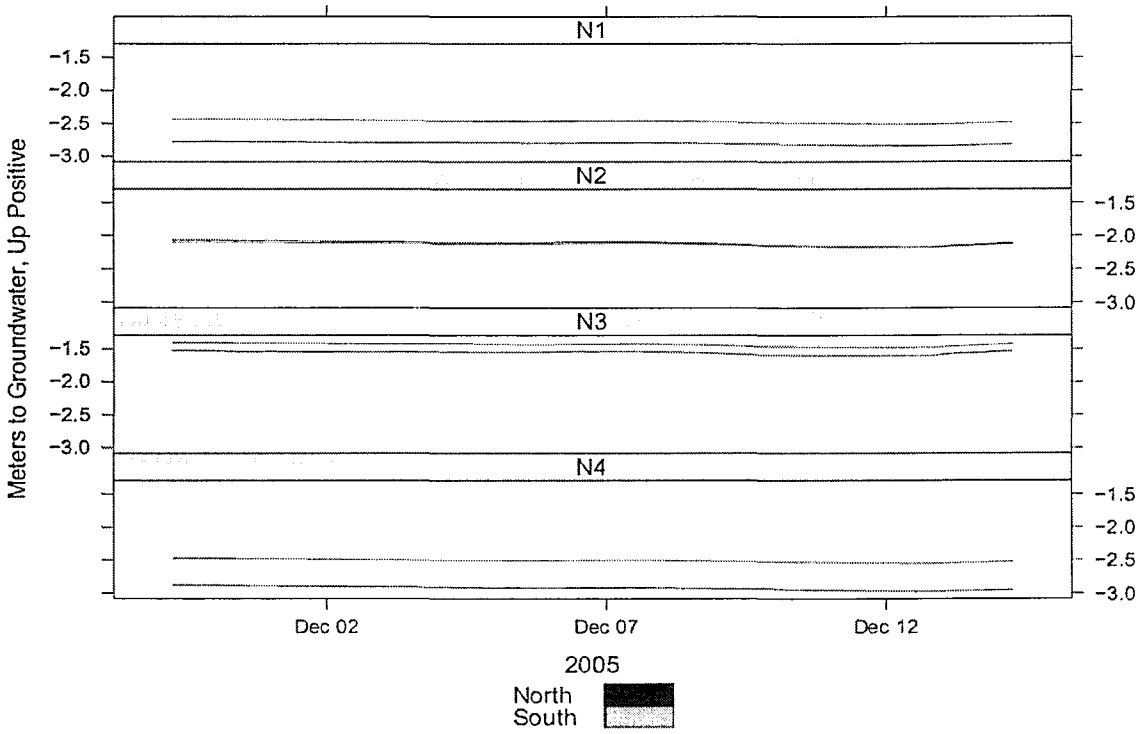

Figure 2: North Site Wells - Winter Groundwater Time Series

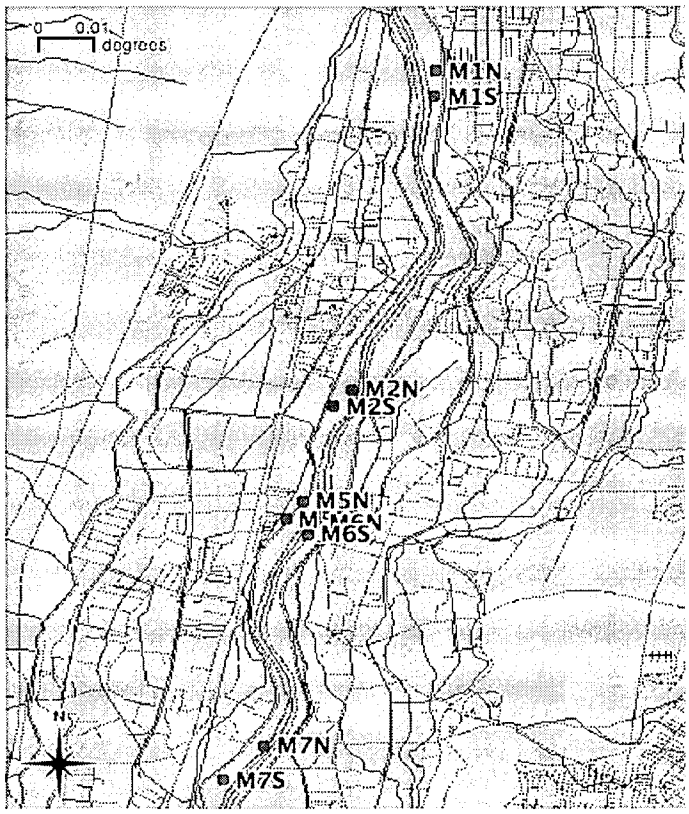

Figure 3 Middle Site Well Locations

Well ID	Meters to River
M1N	158
M1S	72
M2N	125
M2S	312
M3N	85
M3S	78
M4N	59
M4S	69
M5N	134
M5S	198
M6N	118
M6S	104
M7N	68
M7S	211

Table 3: Middle Site Well Calculated Distances to Riverbank

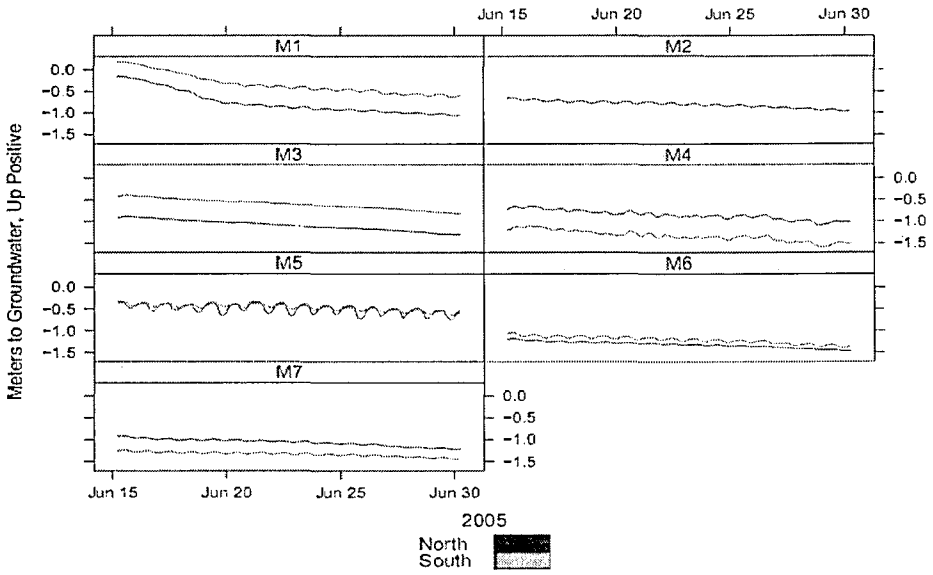

Figure 4: Site Wells - Summer Groundwater Time Series

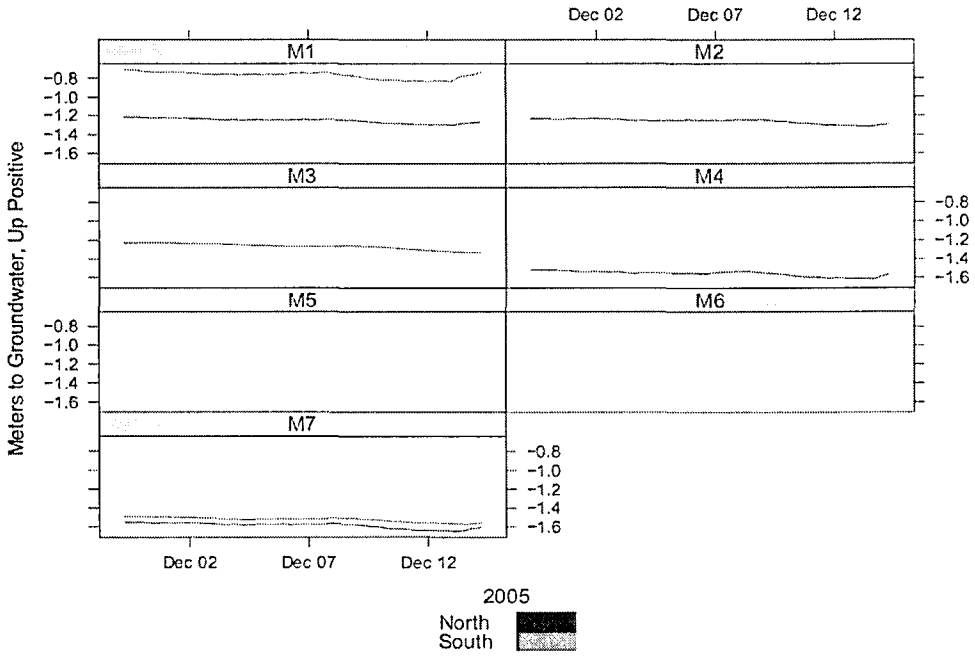

Figure 5: Middle Site Wells - Winter Groundwater Time Series

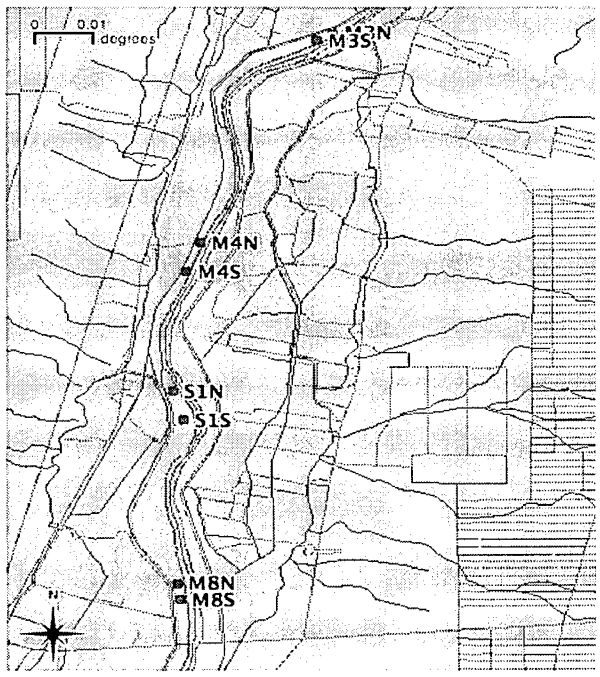

Figure 6. Middle and South Site Well Locations

Well ID	Meters to River
S1N	107
S1S	174
S2N	99
S2S	64
S3N	NA
S3S	NA
S4N	NA
S4S	NA
S5N	NA
S5S	NA
S6N	NA
S6S	NA
S7N	120
S7S	109

Table 4: South Site Well Calculated Distances to Riverbank

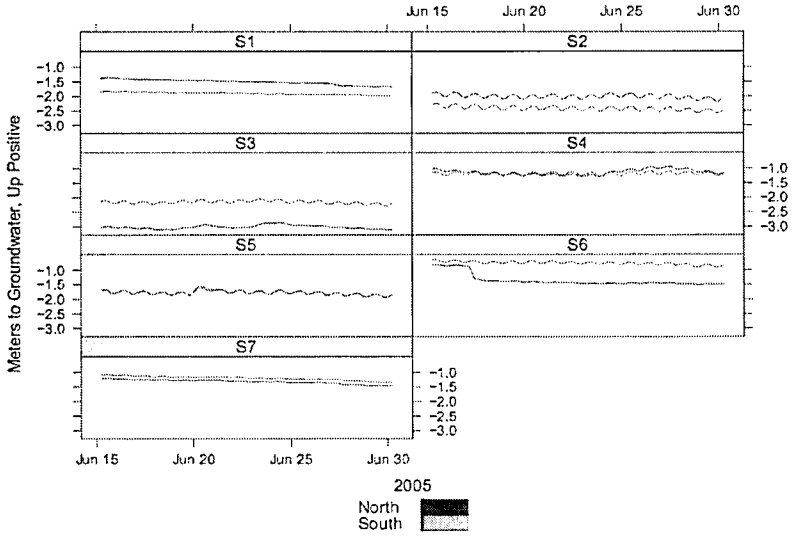

Figure 7: South Site Wells - Summer Groundwater Time Series

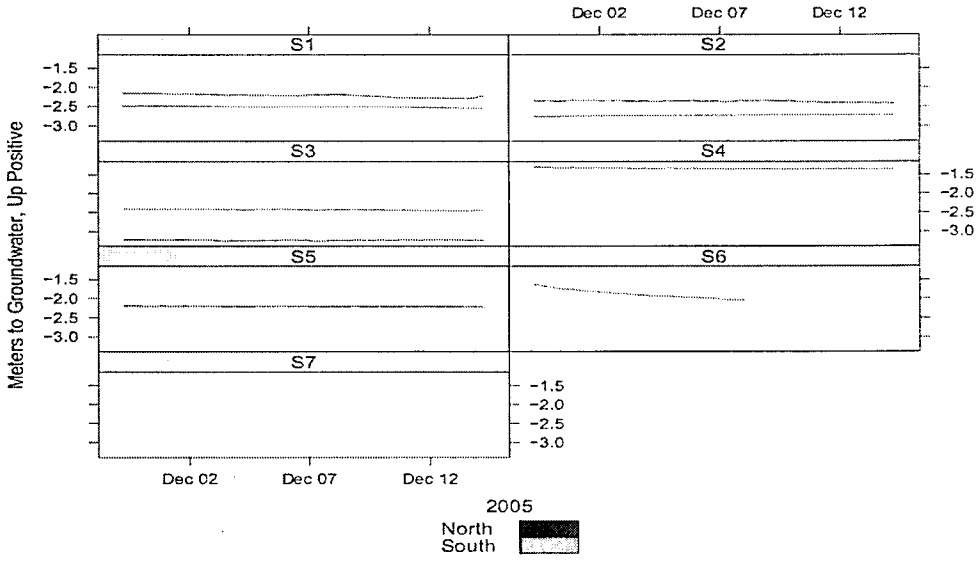

Figure 8: South Site Wells - Winter Groundwater Time Series

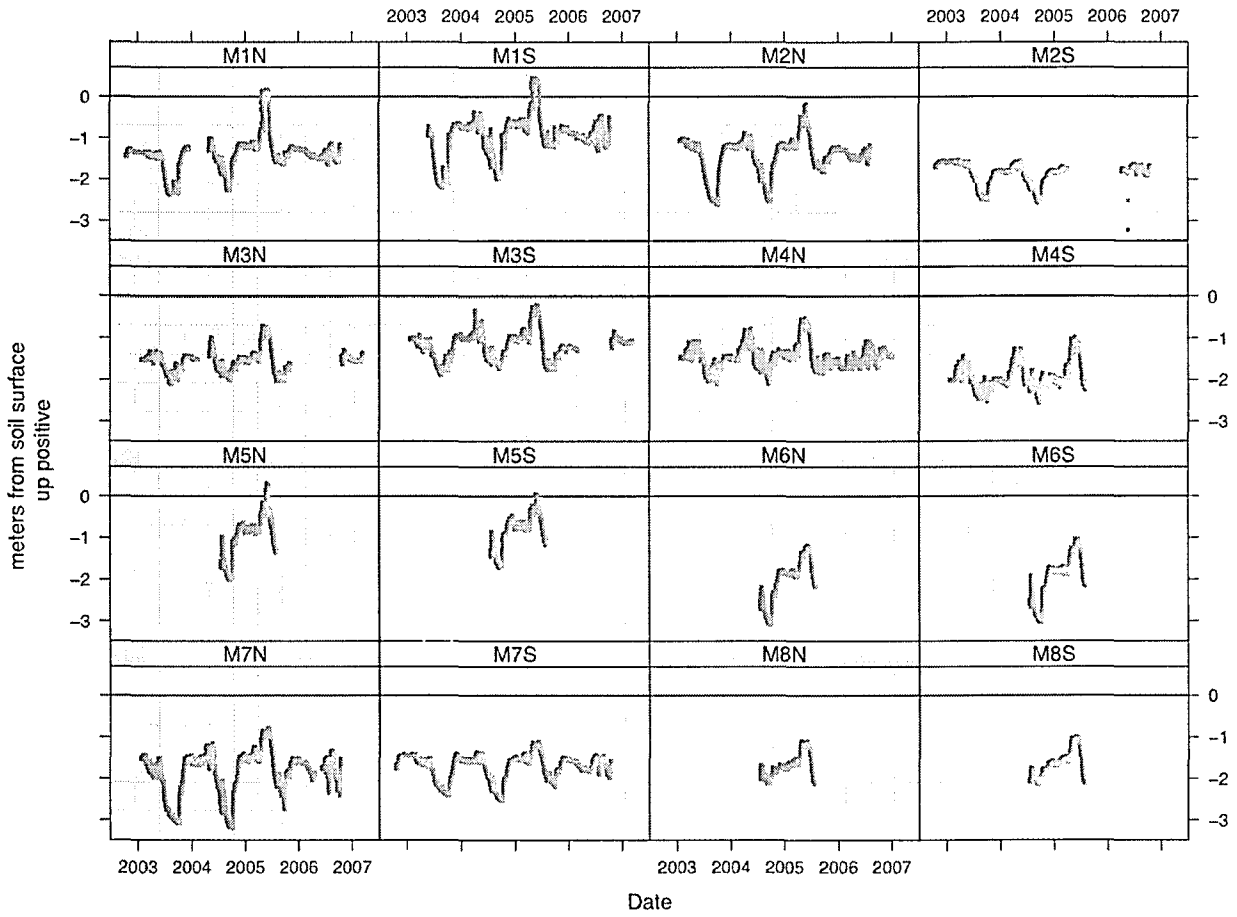

Figure 9: Preliminary Overview of Full Groundwater Record, Middle Block

The Groundwater Hydrological Regime in the Middle Rio Grande Bosque

Groundwater in the MRG bosque is directly influenced by several primary factors:

- The primary source of groundwater in the MRG bosque is the main river channel, which is influenced in turn by regional seasonal hydrography, including high flows from spring snow melting and summer monsoon rains (Finch et al. 2004)
- Throughout much of the MRG, the main river channel is situated above the Middle Rio Grande Conservancy District's (MRGCD) riverside drains. Where the river lies above these drains, main channel water follows the hydraulic gradient through the ground into the drains. As such, groundwater that is riverwards (inside) of the riverside drains is much more influenced by river flow than groundwater that is not riverwards (outside) of the riverside drains(Crawford et al. 1993).
- Evapotranspiration, predominantly by woody phreatophytes, consumes a significant but difficult to quantify amount of groundwater in the MRG bosque (Dahm et al. 2002) (Cleverly et al. 2006)

Spring Floods

Historically, the MRG bosque was a flood-driven ecosystem that often experienced very high river flows in early spring caused by melting of mountain snow. In 2005, a very large spring flood pulse was observed in the MRG, as seen in Figure 13. Figure 14 shows the coherence of this pulse from north to south for 2005.

However, not every year exibits such a spring flood pulse. On one hand, hydrological control structures such as Cochiti dam attenuate the amplitude of the spring flood pulse (Crawford et al. 1993). On the other hand, a negative correlation has been shown to exist between winter snowpack, which determines the spring flood pulse, and summer monsoons(Gutzler 2000). In Figure 16, a comparatively weak spring flood pulse is followed by an extraordinarily strong summer monsoon.

Summer Monsoons

Figure 11 and Figure 12 illustrate characteristic precipitation patterns near the northern and southern limits of the study area during the study period. The summer months, particularly July and August, exhibit significantly higher average monthly precipitation than other months.

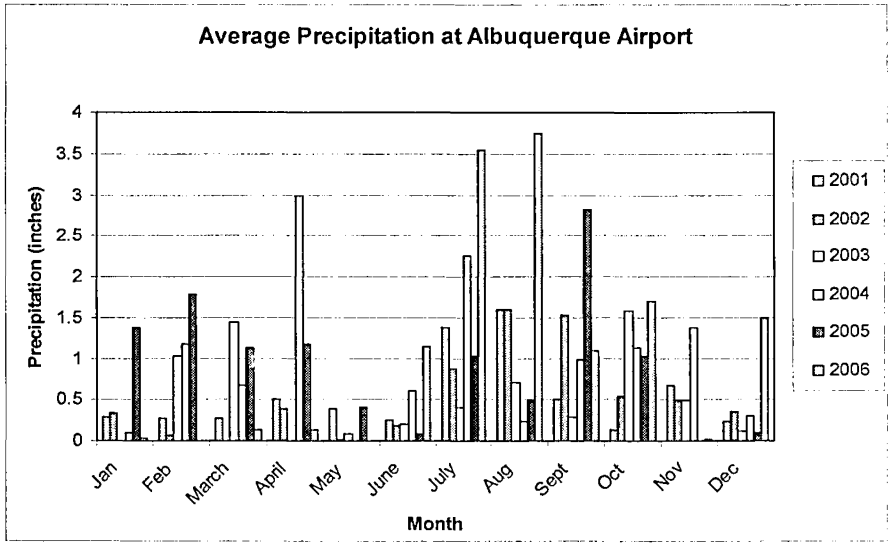

Figure 10. Average monthly precipitation at Albuquerque Airport

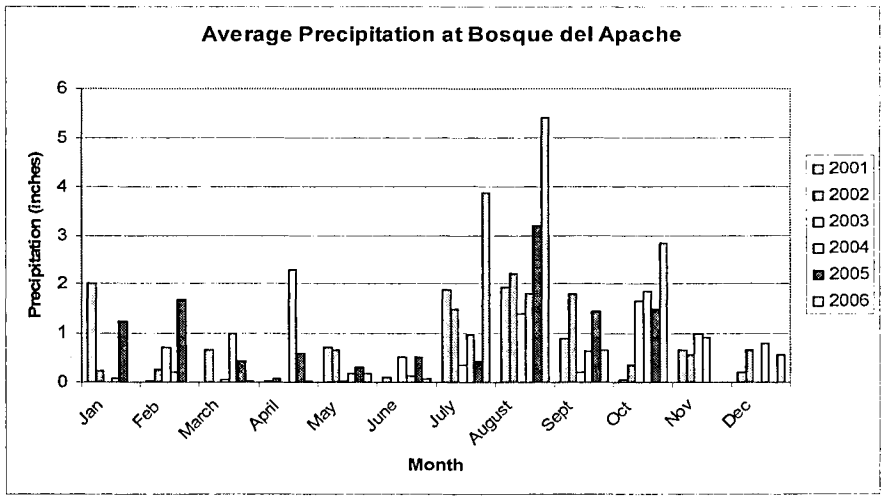

Figure 11. Average monthly precipitation at Bosque del Apache,

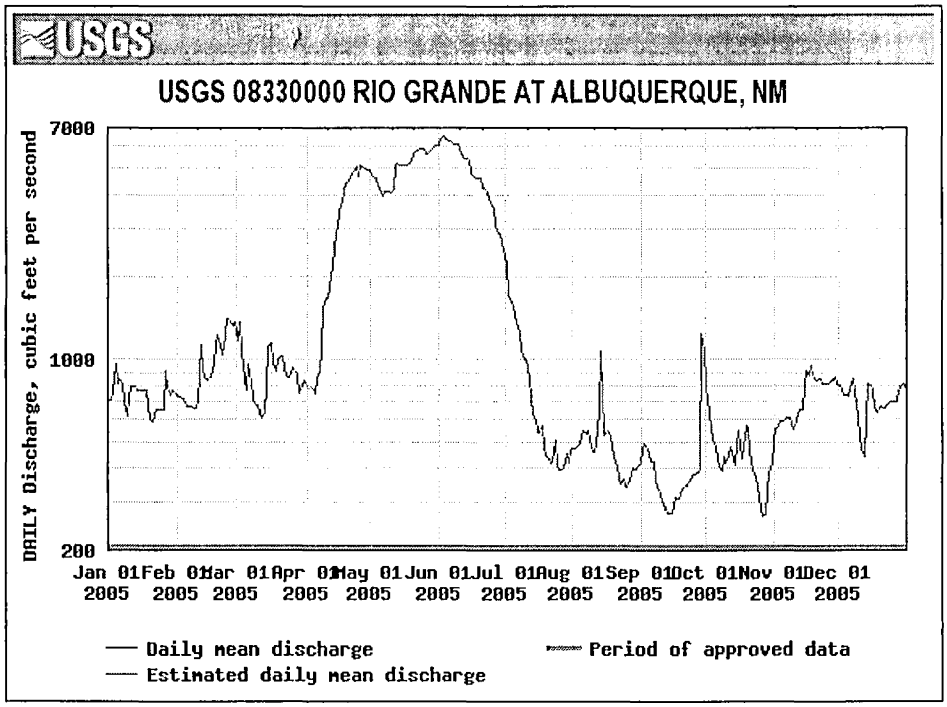

Figure 12. Daily Discharge of the Rio Grande at Albuquerque, 2005

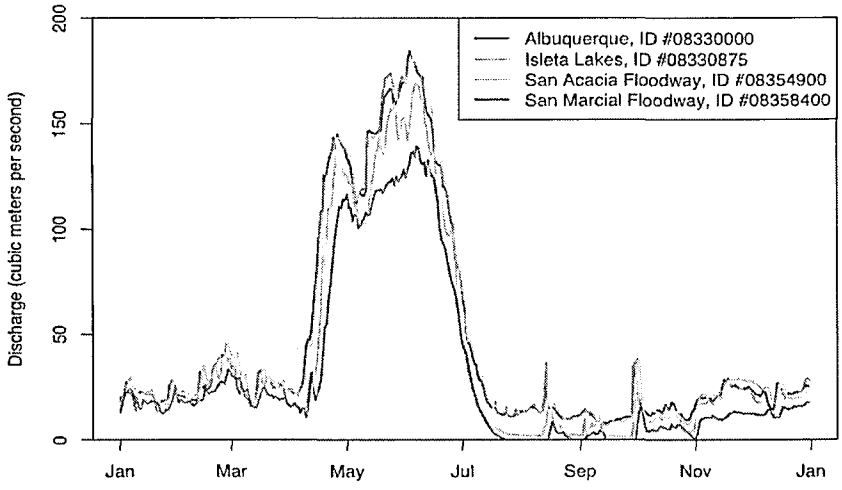

Figure 13. Daily Discharge of the Rio Grande from North to South, 2005

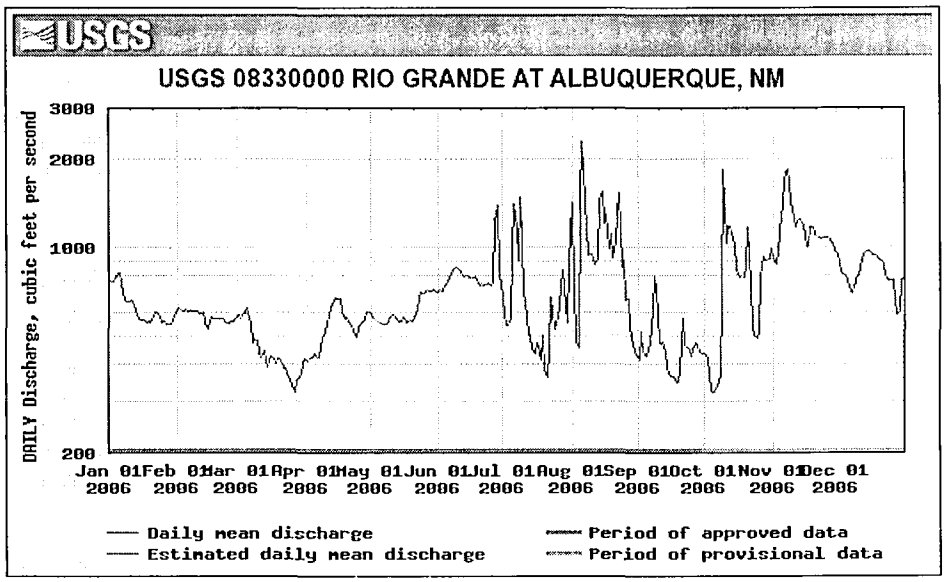

Figure 14: Daily Discharge of the Rio Grande at Albuquerque, 2006

Figure 15 shows daily discharge of the Rio Grande at Albuquerque in 2006, a year that exhibited a weak spring flood pulse and a strong summer monsoon. Figure 16 shows the close relationship

of groundwater levels to the river discharge in 2005.

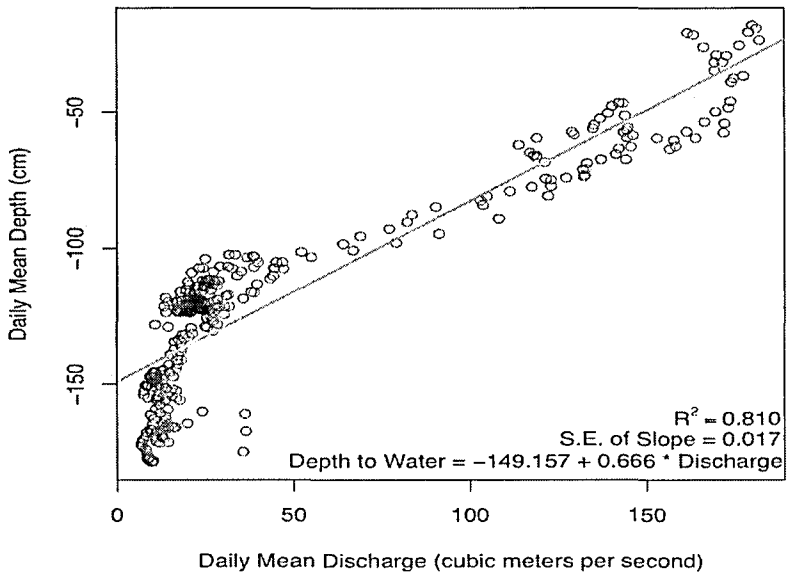

Figure 15. Linear Model of Response of Groundwater to River, Middle 2 North Well, 2005

Fire in the Middle Rio Grande Bosque

As groundwater levels have dropped and spring flood pulses have been attenuated by hydrological control structures in recent years, native species have faced increasing stress. One powerful influence in the MRG bosque in recent years has been wildfire. Wildfires tend to favor non-native woody plant species such as saltcedar over native woody plant species such as cottonwood (Smith et al. 2004). While the causes of individual wildfires often remain unclear, wildfires often occur where the bosque comes into close contact with humans.

On the 16th of June 2006 the southern half of treatment site North 3 suffered a catastrophic wildfire where it made contact with Interstate 25, just north of Isleta Pueblo. The following pictures provide a glimpse at the devastating effects of this fire. The mature cottonwood stand that occupied the site suffered very high mortality from the wildfire, as seen in Figure 17. In the subsequent spring, two species of fast-growing non-native annuals, kochia (*Kochia scoparia*) and another unidentified annual, rapidly colonized the site and largely excluded native vegetation, as seen in Figure 18.

Figure 16: North 3 South Well, Autumn 2006, Post Wildfire

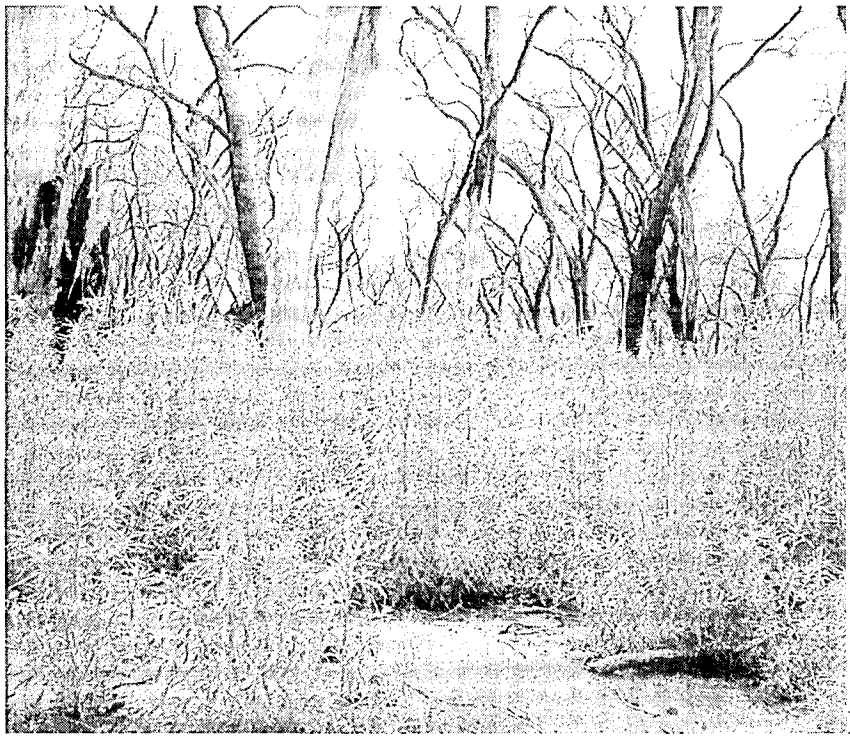

Figure 17: North 3 South Well, Spring 2007, Wildfire Regrowth

Discussion

Research Concerns and Opportunities

Technical Difficulties

The groundwater hydrology portion of the FRS has encountered problems with aging and malfunctioning equipment that has resulted in data loss. In addition, incomplete technical understanding of monitoring equipment and software in the past has resulted in data loss due to operator error by both UNM and FS personnel. A full audit of equipment and software has been conducted. Replacement equipment will be purchased with grant money obtained from the UNM's GRD grant. Data collection and maintenance protocols have been established to eliminate operator error.

Daylight savings time boundaries created difficulties in properly aligning multiple data files. Algorithms have been developmed to facilitate automated alignment of data files to create an accurate and continuous record.

Recent Site Developments

The North 3 fire of 2006 damaged the North 3 South wellhead and the logger cable, yet both the logger and its data survived intact. This data has potential to provide information about the immediate responses of level and temperature groundwater to wildfire on the MRG. In addition, this site provides a rich opportunity for the response of a riparian ecosystem to catastrophic wildfire.

Recent vandalism in the Los Lunas region resulted in costly damages in 2007. Two well caps were forcefully removed in early 2007 with firearms and one logger was stolen. In addition, significant vandalism was discovered at nearby MRGCD levee road gates. All vandalism was reported both to the MRGCD and the Los Lunas police, who filed a police report.

Analytical Challenges

In the MRG bosque, both the river and the shallow unconfined aquifer exhibit large seasonal and yearly variability. Both the river and the shallow aquifer have been or are expected to be impacted significantly by land use and climate change. Both the river and the shallow aquifer effect and are effected by trends in the riparian ecosystem. Such high degrees of nonlinearity and interdependency complicate the detection and quantification of linear correlations. Ongoing monitoring of multiple ecological parameters such as that done by the FRS provides manages and researches with a powerful tool to observe emerging trends as well as quantify existing trends.

Future Work to be Performed

The following future work is to be executed during 2007-2008:

- use of UNM grant funding to replace non-functioning equipment including data loggers;
- use of UNM grant funding to survey the elevations of wells with low cm accuracy rental GPS;
- statistical analysis of correlation between groundwater levels and MRG discharge;
- statistical analysis of groundwater time series, including inter-site, inter-block, and summer/winter comparisons of groundwater levels and temperatures;
- preparation of 2007 Annual Report as specified in the Joint Venture Agreement between the WRP the RMRS;
- preparation of professional projects by Lynda Price and Christian Gunning pursuant to WRP degree requirements.

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